McGINNIS

Anatomy and
Physiology of
Branchipus Serratus

Science
B. A.

1902

NOTES ON THE ANATOMY AND PHYSIOLOGY

OF BRANCHIPUS SERRATUS (Forbes)

by

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Submitted for Degree of Bachelor of Arts

in the College of Science

in the

University of Illinois

Presented June, 1902

UNIVERSITY OF ILLINOIS

June 7 1902

THIS IS TO CERTIFY THAT THE THESIS PREPARED UNDER MY SUPERVISION BY

Mary D. McGinnis,

ENTITLED Notes on the Anatomy and Physiology of Branchipus serratus (Forbes)

IS APPROVED BY ME AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE

OF Bachelor of Arts in the College of Science.

S. A. Forbes

HEAD OF DEPARTMENT OF Zoology.

Preface

As indicated by the title this paper is by no means an exhaustive treatise on the anatomy and physiology of Branchipus. A good deal has been attempted, but in the time spent on the investigation everything could not be thoroughly carried out. Consequently, there are many gaps which could be filled by further study.

The investigations concerning the reactions to light were carried on in the spring of 1901. The other experimental work, and the work on the anatomy was done in the fall and spring semesters of 1902. The part of the paper dealing with the respiration is written up from data furnished by Miss Miriam Welles; the results of experiments performed by her in the spring of 1901.

Whatever there may be of merit in this paper is due to the careful supervision and kindly suggestions and encouragement of Professor Frank Smith. I owe much to Professor Smith, as well as to Mr. R. E. Richardson and Mr. L. S. Ross, for aid in procuring material. I also want to express my indebtedness to Miss Miriam Welles for the use of her data on respiration.

Contents

PART 1

General Notes on the Habitat and Habits

Branchipus serratus, (Forbes), is a phyllopod which is abundant, in this locality in the spring in ponds and puddles which may be dry for the greater part of the year. It is very similar to B. vernalis, found in the east, and B. stagnatis and B. grubei found in Europe, being distinguished from them by its longer frontal organs.

The genus Branchipus is very closely related to the salt water form Artemia. The Russian investigator, Schmankewitsch, saysthat there are only two distinguishing characters between these two genera. Branchipus has nine segments to the abdomen, and Artemia eight, the last being elongated so that it is equal to two of the preceding segments; and Artemia is parthenogenetic, while Branchipus is not. In fact, this same investigator holds that Artemia is simply a degraded form of Branchipus, changed under the influence of its surroundings, and that Branchipus, on the other hand, is a higher developed form of Artemia, which has transformed in a progressive direction in its fresh water environment.

In the spring before the ice was off the ponds we have collected Branchipus larvae. Under natural conditions Branchipus hatches out about the 1st of March. and ~~they~~ lives until the 1st or middle of May. One of ~~their~~ chief enemies The species is the larvae of the giant water beetle which devours them in large numbers.

Adaptations to Life in Temporary Ponds

Branchipus is quite translucent, and so colored that it can hardly be seen in its native environment, (open ponds with com-

paratively little vegetation), until one has become accustomed to looking for it.

The rapid development of this Crustacean adapts it for the continuance of the species in these temporary ponds, since before it disappears, the 1st or middle of May, it has deposited three or four sets of eggs, or rather embryos.

These embryos are covered by a hard secretion from the cement glands, which makes them admirably adapted to survive the drying up of the ponds in summer and the freezing of the next winter. As soon as they are freed from their icy bonds in the spring they all hatch out at once and are ready to go through the same life cycle.

I believe it is freezing, rather than a long period of quiescence, that is necessary before these larvae will hatch. In the fall before there had been any hard freezing mud was collected from ponds where Branchipus was known to have been abundant in the spring. From this mud no larvae developed, while from mud obtained from the same ponds in the early part of January several specimens developed, and this was nearly two months before they hatch in their natural environment.

The fact that freezing, (or a long period of quiescence), is necessary before these larvae will hatch is an adaptation to life in these ponds. If some such conditions were not necessary there would be nothing to hinder them from hatching at any time during the summer and succumbing to the heat, drought, or voracious enemies.

Food

Branchipus is an omnivorous feeder. Its swimming feet keep up a constant current towards the mouth, and any small particles which thus come into the way of the maxillae are shoveled into the mouth where they are triturated by the mandibles which keep up a continual rocking motion. They swallow mud and particles of sand which are carried to the mouth by the current along with the digestible particles of organic matter. Consequently while the animal is lying on the bottom the alimentary tract is constantly gorged with indigestible matter. In an aquarium which contained a great deal ~~of~~ algae the alimentary tracts of those which were not lying on the bottom were green throughout. I have seen them swarming around both the fresh and decaying gelatinous envelopes of amphibian eggs, from which they were apparently able to disengage particles to feed upon.

Movements, Swimming and Respiratory

The most noticeable of the movements of Branchipus is the constant vibratory motion of the swimming feet.

Whether the animal is swimming or lying quiet its feet are constantly engaged in this regular motion, which is more rapid when swimming than when at rest. It is a sort of wave motion which progresses from the posterior feet to the anterior. The swimming seems to be accomplished by this motion and the bending of the abdomen, the abdomen and the telson acting as a rudder. Branchipus normally swims and lies at rest on its back, but it sometimes swims, or lies on the bottom with the ventral side down.

I have seen it feeding on the bottom with the ventral side down or feeding on a clump of algae or amphibian egg envelopes with the ventral side next these objects. When it is caught in a net, or taken out of the water it seems to wriggle forward for short distances by flexing the abdomen and extending it. The fact that the beating to and fro of the swimming feet has a respiratory function as well as a swimming function is brought out in the experiments in PART II, in which the rapidity of the beats increased with the addition of CO_2 to the water until a certain limit was reached, when the further addition of CO_2 caused the oscillations to cease entirely.

Reproductive Habits

I have seen very little published, concerning the reproductive habits of any species of Branchipus, and some of the things that I have noted have not been verified by any one else, so far as I know.

The male swims straight toward the female, often from one side of the aquarium to the other. If the eggs are in the ovary, or in the paired external sacs, (see anatomical description), the male clasps the female just in front of the external pouch and holds her firmly. The female struggles considerably, and the two swim about together for more than a minute in some cases. The act of copulation lasts about a minute.

If the eggs have passed over into the uterus from the paired external sacs the male clasps the female, but immediately lets her go.

However full these paired sacs and the ovaries may be, the eggs will not pass over into the uterus until copulation has taken place. In one case I saw copulation take place and in a little more than an hour the eggs had passed over into the uterus. In another instance copulation took place at three o'clock, and at four the eggs were in the uterus. A specimen that was kept isolated from March 29 until April 4 had the paired sacs and the ovaries very full of eggs, yet none came over into the uterus until a male was put in the aquarium. The next morning the eggs were in the uterus. I repeated this experiment with two other individuals with the same result, while another individual in which copulation had taken place March 29 and which had been kept with a male, had deposited its third lot of eggs by April 7. A specimen which was kept isolated from March 13 until May 4 had very full paired sacs, yet no eggs passed over into the uterus.

The females with eggs in the uterus kept as close to the bottom as possible, apparently to keep away from the ever attacking males.

PART II, EXPERIMENTS

Behavior with Regard to Light

One of the most noticeable of the reactions of Branchipus is the positive response to light. This can be easily observed in the laboratory. When these animals are kept in an aquarium one will always find the greatest number of them on the side of the aquarium next to the light. If a screen be erected between the aquarium and the light in such a way as to make a light portion and a shaded portion they will swarm out from the shaded area into the light. If two screens be put up, making two shaded regions with a light streak between them they will collect in the streak.

The following experiments on the subject of the reactions of Branchipus to light stimulus were undertaken with six objects in view:

1. To determine whether the reversal of reaction which Miss Towle described for Cypridopsis vidua (American Journal of Physiology, March, 1900) occurs in Branchipus.

2. To determine how they behave with regard to the direction of the light ray.

3. To determine the relation of the rate of movement to the intensity of light.

4. To determine whether they exhibit any individuality.

5. To determine how they react to light of different colors.

6. To find out the effect of exposure to dark.

Reversal of Response

Miss Towle's experiment led her to believe that in Cypridopsis vidua a peculiar reversal of response was caused by contact. An individual placed in a trough with the light at one end usually moved toward the light. If, before it reached the bright end and while it was still moving in that direction, the light was changed to the opposite end, the animal turned and swam toward it, thus keeping up its positive heliotropism, which could be maintained indefinitely in this way, but as soon as the animal was allowed to come in contact with the end toward the light, it turned and swam away. If the light was again changed while the animal was swimming away from it, this negative response was maintained as the positive had been. When the animal touched the end of the trough away from the light it again became positive.

My results with Branchipus did not agree with those of Miss Towle with Cyprodopsis. Yerkes, in a paper published in the American Journal of Physiology, December, 1900, gives an account of some experiments on Daphnia and Cypris in which he arrived at results contrary to Miss Towle's.

My method of procedure was as follows:

A trough, in the shape of a half cylinder, five and a half feet long, and five and a half inches in diameter, painted black on the inside and having glass ends, was placed on the table in the dark room and filled about half full of water. The light, (a Welisbach burner), was placed at one end on a level with the trough so that the rays went directly through the glass end, ap-

proximately parallel with the long axis of the trough. A specimen of Branchipus was put in at the darker end. It took almost a straight course toward the light. Here it swam around for a few seconds after coming in contact with the glass end, and then started in a negative direction with as straight a course as it had taken in the positive direction. After reaching the negative end and swimming around there indefinitely for a few seconds it again seemed to become positive and went straight back to the light. Two other individuals were tried. They acted just as the first one had done and kept up this peculiar reaction during the two hours that they were experimented with on this particular day. The natural conclusion was that Miss Towle's results had been confirmed.

Next day, however, when the same thing was tried again under what seemed to be exactly similar conditions, the specimens used did not behave at all like Miss Towle's specimens of Cypridopsis had done. This time there was only a slight tendency to respond to the light at all. They went into the end away from the light almost as readily as into the bright end, or they swam around in some intermediate region. This same thing was tried several times, and from the repeated trials I could see that there was a slight tendency to go toward the brighter end. Although they often came in contact with the end, there was nothing to lead one to suppose that this caused any change of response. They often swam away from the light, but they did this just as readily before touching the end as afterward.

Since the reactions seemed to be so slight in the trough, I thought that perhaps the straight courses which they took to and from the light must be due to something else, perhaps the shape of the trough. Accordingly the trough was discarded for a glass aquarium ten inches long by seven inches wide. Black screens were put up around it on two sides and one end. The end without the screen was turned toward the light. In the aquarium there was a slight positive response. Most of the animals went to the brighter end, though they went into the opposite end readily and oftentimes stayed there quietly. There was not the slightest indication of reversal of response.

The fact that there was very little difference in the intensity of the light in the two ends of both the trough and the aquarium suggested that a greater difference might cause a more decided response.

A black screen was put up between the aquarium and the light in such a way that the aquarium was partly shaded. Now the animals swarmed out of the shaded region very quickly.

To make a still more decided difference a large square black pan was used. The light was elevated about ten inches and placed in the vertical plane about two inches from the corner of the pan. The pan was covered by a heavy cardboard which had a two inch square cut out of the corner next to the light. The cover was raised and a specimen of Branchipus was put in at the corner diagonally across the pan from the light. It quickly responded positively to the light, and when it came into the little square bright spot was effectually trapped. The dark shadow was as effective a

barrier as a partition would have been.

Branchipus, under these conditions, responded positively to the light, in all except two cases. I have records for more than thirty trials of different individuals. One was a male which did not respond at all, the other a female which responded negatively. On trying again next day, however, both responded positively. It made no difference how often they came in contact with the sides of the pan, they did not show any reversal of response. (The fact that the animals in the pan without the cover and with the light in the same position acted just as they had done in the aquarium without the screen and with light on a level with it, is sufficient evidence that the elevation of the light had nothing to do with the difference in the character of the response.)

Behavior with Regard to the Direction of the Light Ray

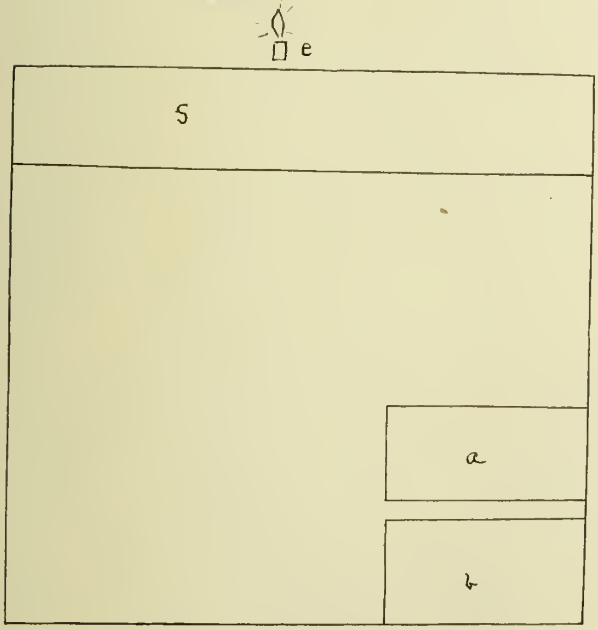
Almost any one who has performed any experiments on the subject of the effects of light on living organisms has tried to solve the problem whether the particular organism with which he experimented was photo-tactic or photo-pathic, i.e., whether it oriented itself according to the direction of the ray of light, or whether the reaction was in response to the intensity of the light, independent of the direction of the rays. It is undoubtedly true that these two factors act together in some cases. The behavior of some animals would seem to indicate that the reaction is due to the direction of the ray regardless of the intensity, and Loeb describes some experiments with a species of Planarian which he says is not oriented by the light ray, but which is sensitive to the intensity of the light.

From previous experiments, and from experiments with the object in view of determining the behavior of Branchipus serratus with regard to the direction of the ray, it is evident that the reaction of these animals is due in a great measure to the intensity of the light.

To be able to say conclusively that Branchipus is not at all influenced by the direction of the ray would require apparatus in which all refraction and all reflection could be taken account of, and in which something has been introduced to regulate the influence of the intensity and not that of the ray. Professor Smith makes a very plausible criticism on the India ink prism used by so

many experimenters to overcome the influence of the intensity of light without effecting the direction of the ray. He says that since the India ink consists of finely divided particles held in suspension, the light passing through it would be refracted in all directions.

After it was too late to use it I thought of some apparatus which I believe would reduce the various sources of error to a minimum. Some time I want to verify the apparent results of my crude experiments with this apparatus. These experiments seem to indicate that Branchipus is not influenced by the direction of the ray of light.



On March 27 some experiments were performed with the apparatus shown in the diagram. (a) and (b) are two square glass dishes placed in the large pan used in the other experiments, at the positions indicated. They form the channel (d). The light (e) is placed exactly in the middle of one side of the pan. A heavy cloth covers the pan leaving the light area (s).

The specimens were put in at the channel and the direction of their courses to the light noted.

1. Four specimens were put into the channel. Three of them went straight to the light, and the other took an indefinite zig-

zag course to the light.

2. Five specimens were put in at once. Two of them took more or less semi-circular courses. The other two went to the light, but I did not see the directions that they took.

3. Four were put in this time, two took semi-circular courses and two took diagonal courses to the darkest corner.

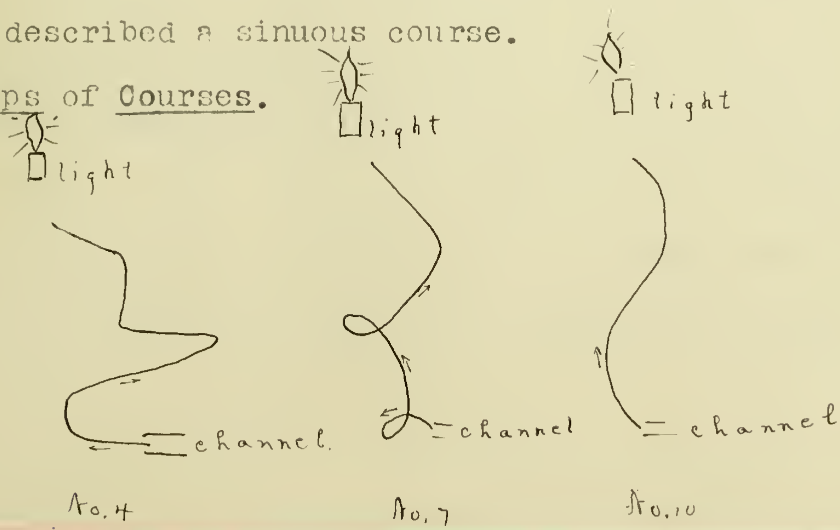
4. One was put into the channel, and it took a diagonal course to the light area.

When the specimens came into the light space they took any direction with regard to the light.

On March 29 the experiments of March 27 were repeated, but only one specimen at a time was put into the channel and a map was made of each course to the light. These maps are not drawn to scale, but it shows practically the directions taken by each specimen and, approximately, the relative distance traveled in each direction.

No. 1 went straight to the light, No. 2 took a diagonal course, No. 3 went straight, No. 4 zig-zag, No. 5 semi-circular, No. 6 straight, No. 7 zig-zag, No. 8 straight, No. 9 diagonal, No. 10 described a sinuous course.

Maps of Courses.



Relation of Rate of Movement to Intensity of Light

Thinking that I had observed Branchipus moving faster in a bright light than in a less intense light, a series of experiments to prove this were performed.

First they were tried in a square glass aquarium ten inches long, with a white paper underneath it, marked off in inch lengths. A lamp was placed at one end and a streak of light about an inch wide was made to pass through the dish parallel to its long axis. Now as the animals traveled up and down in this streak a record was kept of the time it took to cross each inch division. The aquarium was so short, and the light of the streak was so nearly uniform that there was very little tendency to go toward the brighter end of the streak or to travel very far in either direction. Consequently, I was unable to prove my supposition with this short dish. However, the results were in the affirmative.

I have tabulated four trials of the same individual going toward the light, and four trials going from the light. The number at the top of each column refers to the number of the division, beginning at the darker end and going toward the light. As was mentioned before the specimens only went short distances without stopping or swimming around indefinitely, and this accounts for the fact that I have not data for trips, the entire length of the dish. Sometimes the specimens went farther than at others, and hence the tables show some trips longer than others.

Table I

Toward light		1	2	3	4	5	6	7	8	9	10
1st trip	Sec. per inch	3	3	2							
2d "	" " "	3	2	2	1	1	1				
3d "	" " "	3	3	2	2	1	1	1			
4th "	" " "	3	2	2	1						
	Average	3	2.5	2	1 1/3	1	1	1			

Table II

From light		1	2	3	4	5	6	7	8	9	10
1st trip	Sec. per inch								4	5	3
2d "	" " "						4	3	2	2	2
3d "	" " "						3	4	3	4	3
4th "	" " "								4	5	3
	Average						3.5	3.5	4.25	4	2.75

In order to have them take longer trips through a greater difference of intensity, the aquarium was discarded for the long trough, marked off in divisions two inches in length. On account of the shape of the trough the animals took comparatively straight courses, and they often went considerable distances. Consequently more satisfactory results were obtained with the trough. Although for small distances it is not very apparent, for long distances when they travel the greater part of the length of the trough it

is evident that they travel faster in the light end. The tabulation of the results simply shows that the tendency was for the rate of movement to grow faster as the animal approached the light. Whenever the animal started to go toward the light the record of its rate of movement was begun, but no record was kept of the starting point. If this had been done I feel sure that the average of the time required to travel the length of the successive divisions would have been more satisfactory as well as more convincing. I have recorded each trip as beginning at the division No. 1. This does not necessarily mean that any of them did this, but simply that the individuals were traveling toward the light. I did not get any data going away from the light in the ~~trought~~ because the animals did not go far enough in this direction. These trips are not all for the same individual as was the case in the aquarium. (See Table III, on following page)

Table III

Toward light

Trip 1, Sec. per in.	20	19	17	11	14	15	12	12	14	21	10	11	10	11	9	8	9	9	11	8	6	7
" 2 " " "	17	24	11																			
" 3 " " "	14	17	12																			
" 4 " " "	11	16	18																			
" 5 " " "	15	16	18	25	18	14	15	12	10	18	16	9										
" 6 " " "	7	6	6	5																		
" 7 " " "	5	3	4	4	3	4	3	5														
" 8 " " "	3	4	4	3	3																	
" 9 " " "	27	15	8	11	7	7	9	9	4	6	7	11	3	4	3	2	2					
" 10 " " "	17	15	15	13																		

Individuality

Some experiments were performed with the object of finding out whether Branchipus showed any individuality in the reactions. I concluded from the data tabulated in Tables lV, V, and Vl that there was not much indication of individuality, if any at all, except that males were much more prompt to respond to light than females. That males were more sensitive than females, was not only observed in these experiments, but had been apparent in the previous experiments. The square black pan with the cardboard cover, which was described in a previous experiment, was used for this. The time it took in seconds for the animal to travel from the dark corner diagonally across the pan from the light, a distance of twenty-eight inches, is the time recorded.

The objection may be made that these animals do not take straight courses to the light under these conditions. However, I believe that the average of a great many trips for each individual ought to be a pretty fair test of the individuality. I have not enough data perhaps, but simply give it to show what has been done on the subject.

IV

Female	Ex. 1	Ex. 2 March 1	Ex. 3, 19 1/2° March 4	Average
Time	Sec.			
1st Trial	125	70	90	95
2d "	120	38	40	66
3d "	140	30	35	70 1/3
4th "	140	39	61	80
5th "	80	40	60	60
6th "	50	50	35	41 2/3
7th "	40	29	35	34 1/3
8th "	28	37	60	45
9th "	50	50	50	50
10th	35	50	55	46 2/3
Average	81.8	43.3	52.1	

V

No. I Male	Ex. 1 Sec.	Ex. 2 Mar. 1, '01	Ex. 3, 20° C. Mar. 4, '01	Average
Time 1st Trial	35	65	38	46
2d "	38	70	15	41
3d "	15	40	25	26 2/3
4th "	17	30	50	32 1/3
5th "	18	32	25	25
6th "	20	60	20	33 1/3
		40	35	37 1/2
		40	25	32 1/2
		30	15	22 1/2
		40	10	25
Average	23 5/6	44.7	25.8	

VI

Male, No. 2	Ex. 1	Ex. 2	Ex. 3 Mar. 1	Ex. 4 Mar. 4, 19 1/2° C.	Average
Time	Sec.				
1st Trial	5	15	58	55	42 2/3
2d "	6	15	60	38	37 2/3
3d "	6	20	56	41	39
4th "	10	17	60	25	34
5th "	10	18	55	26	33
6th "	15	20	65	26	37
		15	65	38	39 1/3
		15	74	30	39 2/3
		13	60	30	34 1/3
		16	80	28	41 1/3
Average	8 2/3	16.4	63.3	33.7	

To confirm the statement that the males were more sensitive than the females I tried five males and five females in the large pan in the same way as in the previous experiment.

Below are the figures showing the time required by each individual to come to the light.

March 27, 1901

Male No. 1	40 seconds
Female No. 1	100 "
Male No. 2	70 "
Female No. 2	130 "
Male No. 3	50 "
Female No. 3	180 "
Male No. 4	60 "
Female No. 4	Negative
Female No. 5	120 seconds
Male No. 5	No reaction minus or plus

March 29, 1901

Male No. 5	45 seconds
Female No. 4	120 "

On another day the experiment was repeated and the following results arrived at.

Females

No. 1	90 seconds
No. 2	92 "
No. 3	Did not respond
No. 4	100 seconds
No. 5	Did not respond
No. 6	80 seconds
No. 7	5 minutes
No. 8	5 "

Males

No. 1	120 seconds
No. 2	30 "
No. 3	60 "
No. 4	55 "
No. 5	63 "
No. 6	40 "
No. 7	20 "
No. 8	70 "

Behavior with Regard to Light of Different Colors

From the experiments which were performed to determine the behavior with regard to different colors, it is evident that Branchipus responded positively to blue light, and negatively to red. In the first experiments colored glass was set up against the side of the square aquarium and the light placed equally distant from the ends of the aquarium, at a distance of about three feet. All the white light was shut out by means of black screens and all the light that came into the aquarium from the sides came through the colored glass. The pieces of glass were cut of such a size that two pieces just covered the side of the aquarium. When blue, with yellow, red or violet glass was put up the animals would collect in the blue light. With blue or green they went into the green almost as readily as the blue.

This was not a very satisfactory experiment since the relative intensities of the light which came through the different colors of glass were not known.

Next colored solutions were tried. These could be made so that light coming through them would be of the same intensity. The only means at hand by which this could be tested was a photometric screen. This was not a very accurate method for light of different colors, since the eye had to be depended on to detect the differences in intensity. But readings taken independently by three different persons were practically alike. Only blue and red solutions were used. For the blue an ammoniacal solution of copper sulphate was used, for the the red, potassium dichromate.

The solutions were put into rectangular glass cells. These cells were now tested by means of the photometric apparatus. The red solution was called standard, and the blue was diluted until the amount of light coming through the blue was just a trifle less than that coming through the red. The blue light was left slightly less intense than the red, so that if the expected reaction did take place and the animals went into the blue light, even though it was slightly darker than the red, it would be even more conclusive than if the same reaction took place with the red and blue lights of exactly the same intensity.

The cells were placed against the side of the aquarium just as the colored glass had been, and the light placed in the same position as with the colored glass. Thus one-half of the aquarium was thus lighted with blue light and the other with red. Several specimens were put into the red half. They immediately swam into the blue. They often came up to the red, but turned quickly and swam back into the blue. If at any time they accidentally swam into the red they seemed uneasy until they could get back into the blue. When the animals had all collected in the blue light, the cells were changed about, and the half of the aquarium that was formerly lighted through the blue solution was now lighted through the red and the animals were all in the red half. They quickly swam into the blue half which they had avoided while it was red. This was repeated a great many times with the same results. To light of different colors, as well as to white light, the female is less sensitive than the male.

Effects of Exposure to Dark on Character of Reaction to Light

Two sets of experiments were tried to determine the reactions to light after more or less prolonged exposure to dark. One series was to determine the kind of reaction after short exposures of from twelve to fifty-six hours. The other was to determine how some specimens reared in the dark would react. After twelve hours in the dark the two specimens used reacted to light as they normally do. The average time for the trip from the dark corner diagonally opposite the light to the lighted corner was 39 seconds in the one case, and 57 1/2 seconds in the other.

After an exposure of four specimens for twenty-eight hours, two responded about as normally. The average time for the trip from the dark corner in one case was 42 seconds, and in the other 64 seconds. With a third specimen the average time was 121.5 seconds, which is much slower than is usually the case under normal conditions.

The fourth specimen was a female which was from six to ten minutes in coming to the light. This was very slow even for a female.

Four males were exposed to darkness for fifty-six hours. The average time for No. 1 was 304 seconds. No. 2 did not come to the light for ten minutes, but when put in the light did not go back into the shadow, hence it was not negative to the light. No. 3 reacted like No. 2, and No. 4 did not come to the light. When put

in the light it swam around there for six minutes and then went back in the dense shadow to the far edge of the pan.

In my next experiment with four specimens of Branchipus reared in the dark, I found that they responded to light just as Branchipus which are reared under ordinary conditions do.

This led me to believe that the very slow responses after an exposure to darkness for fifty-six hours were due to something else than mere exposure to darkness. I have not had a chance to establish this belief by repetitions of the experiment.

Effect on Development of Rearing in the Dark

On the 16th of March, some Branchipus larvae were put in the aquarium, and this aquarium was set inside of a covered stone jar which was placed in a north east window where it would keep cool. Some of this lot of larvae were allowed to develop in the light in an aquarium placed in the same window, for a check experiment.

By the 3d of April (eighteen days) the specimens grown in the dark were fully developed and the females were carrying eggs. These were much smaller than *Branchipus* usually is when first seen with eggs.

The check experiment was not of much value, for the specimens grown in the light did not even grow as large or develop as soon as those grown in the dark. There must have been some unfavorable condition, perhaps a lack of food.

Summary

1. I concluded from the first experiment that Branchipus showed no tendency to reversal of response, due to contact, and that it was necessary to have considerable difference in the intensity of the light before there was much tendency to respond at all. When one region of the receptacle in which the animal was contained was very much darker than another, there was a very marked positive response to the light.

2. The results of the second experiment were not conclusive, but in this rough experiment, performed with the end in view of determining whether there was any orientation with regard to the light ray, and in the experiments which preceded it, I could see no evidence of such orientation.

3. In experiment three, to determine the relation of the rate of movement to the intensity of the light, the results indicated that the animals moved faster the greater the intensity of the light.

4. In the experiment in regard to their individuality, the scanty data obtained indicated that there was not much, if any, in individuals of the same sex, but that males were considerably more sensitive than females.

5. It was found in the experiment with regard to light of different colors that Branchipus went into blue light more readily than into red light. They seemed to go into blue light more readily than into any other primary color, except green. This latter statement is not conclusive, however.

6. Branchipus reared in the dark react just about like Branchipus reared under normal conditions. The specimens exposed to dark for a period of twelve hours reacted just as they usually do without any exposure to the dark. Those exposed from forty-eight to fifty-six hours reacted very slowly, or negatively, or not at all. I believe some other factor than exposure to the dark caused this reaction. More data will be necessary to determine this.

Behavior with Regard to Different Temperatures

From observing the very low temperatures at which B. serratus hatches out under the ice, I was led to try some experiments to determine the behavior with regard to different temperatures.

The conclusions arrived at from my first experiment are:

1. That: Branchipus reacts negatively to a temperature as high as 28 degrees.

2. That they die very quickly at a temperature of 28 degrees.

3. That the negative response to heat is not as strong as the positive response to light.

For this experiment I used the same long trough as for the light experiments, supported at both ends so that it was about twelve inches above the table. A bunsen burner, turned low, was placed under the trough about six inches from one end, and this end heated to a temperature of about 29 1/2 degrees C. The other end, which was directed toward a window, was shaded by a wide board.

Several specimens were put into the heated region. They all immediately swam out in the direction of the cool end, which was at a temperature of 18 degrees C. They did not all reach the end of the trough where the temperature was 18 degrees, but they swam around in temperatures ranging from 28 degrees to 18 degrees. They were kept in the trough for sometime, but although they went near the heated area (about six inches square) they would not go into it.

These were taken out and eight others put in the heated end which was still at a temperature of 29 1/2 degrees C. Seven of them took their course out of the warm region toward the cooler end as before. One, however, went in the other direction and came in contact with the end of the trough. Before this one could find its way into the cooler part of the trough it died. The screen was now taken down from the cool end and the light allowed to come in. Under the influence of the light the seven specimens came into the extreme end toward the window. The burner was changed to this end and the temperature raised to 28 degrees C. The animals seemed to be much disturbed, but they stayed here in the light end until five of them died. The other two went far enough from the heated region to escape death.

Seven individuals were put in at about the middle of the trough, where the temperature was about 20 degrees. They came into the light warm region and stayed there until they died, showing great uneasiness.

The second experiment simply confirms (1) in the first, with the light factor eliminated.

In order to do away with the light effects entirely, I went into the dark room where all the light was from an incandescent lamp suspended from the ceiling. The center of the square pan which was used in the light experiments was placed directly under this light at such a distance that the light was practically uniform all over the pan, and hence would have no effect on the movements of the animal. Several specimens were put into the pan and

I was able to keep them out of any corner by heating that corner to 28 degrees C. One time when the center of the pan was at a temperature of 32 degrees, three, either accidentally or for some reason that I do not understand, went into this area and died before they could get out.

Again, one corner of the pan was heated to 30 degrees C. Twelve specimens were put into a corner, the temperature of which was 21 degrees C. They were soon scattered all over the pan, with the exception of the 30 degrees corner. They traveled back and forth in every direction, but avoided the warm corner by a radius of from six to eight inches. This area was cooled by pouring in cold water. In two or three minutes there were four in the region that had been cooled, and the other specimens were about uniformly distributed over the rest of the pan. Seven more were put into a corner heated up to 31.5 degrees. They left it immediately, and none came back into it, although the pan was kept in this condition for thirty minutes. As soon as the corner was cooled to a temperature of 23 degrees they came into it readily.

From the third experiment I found that the majority of the animals collected in regions the temperatures of which varied from 14 degrees to 17 degrees. None went into regions where the temperature was higher than 17 degrees, although a few went into areas which was considerably colder.

Ice was used in one corner of the pan, and the temperature reduced right under the ice to 8 degrees C. The corner diagonally from this was heated to 30 degrees C. Several specimens were put

in at the warm corner, and in a short time they were distributed as follows: Seven in a region where the temperature was 16.5 degrees, five where the temperature was 17 degrees, and three in a 12 degree region. Two went under the ice into the 8 degree region, and there were none in any region warmer than 17 degrees. They did not remain distributed in just this way, but the greatest number moved around between the temperatures of 14 degrees and 17 degrees. They were kept in the pan thirty minutes, and during that time they stayed out of regions where the temperature was higher than 17 degrees C.

An experiment with some larvae to determine whether they would develop at very low temperatures had rather interesting results. From this experiment it is evident:

1. That Branchipus larvae live for several weeks at a temperature as low as 1 1/9 degrees C., growing very little if at all.

2. That after having been exposed to such a low temperature, on and brought into a room where the temperature is usually kept between 18 degrees and 23 degrees, they develop, though not as rapidly as they do under normal conditions, and they do not grow as large as they normally do.

On the 13th of March some larvae about three m. m. long were brought into the laboratory. Some of these were allowed to develop in the laboratory, and some were put in cold storage at a temperature of 34 degrees F. (1 1/9 degrees C.). On March 29 I brought a few of the cold storage lot into the laboratory. They were still larvae about 3.5 m. m. long, while those which had been

kept in the laboratory were in the adult stage and measured 10 m. m. They were measured again April 5, and were then 5 m. m. long. April 25 they were 8 m. m. long, and seemed to be perfectly developed. The egg sacs with the cement glands were ~~found~~ formed, but there was only one which showed eggs in the ovary.

On April 18 when I examined those still in cold storage, they were not growing any, but they still seemed to be doing very well. On April 20 I found them all dead. I do not know what happened to them between the 18th and 20th of April, but I do not believe their death was due to the cold storage treatment.

SUMMARY

It is clear from these experiments that Branchipus shows a marked reaction to temperatures as high as 28 degrees, and that at temperatures as high as this the animals die.

Under the influence of light they came into a region where the temperature was 28 degrees, where they stayed until they died. The positive response to light is therefore stronger than the negative response to heat.

The majority remained quiet or swam around without showing any uneasiness in areas where the temperature was from 14 degrees to 17 degrees C. Some of them even went into regions where the temperature was considerably lower (as low as 8 degrees), and did not seem at all restless there, but none went into regions where the temperature was higher than 17 degrees.

Their development can be prevented for a few weeks at least by keeping them at a temperature of 1 1/9 degrees C.

Specimens, after having been exposed to a temperature of 1 1/9 degrees C. from March 13 until March 29, developed in the laboratory where the temperature was usually between 18 degrees and 23 degrees.

They did not develop as rapidly or grow as large as did those from the same lot which were not exposed to cold storage.

Effect of Oxygen in Water upon Rapidity of Oscillations of Appendages

From the experiments to determine what influence, if any, the amount of oxygen in the water exerted upon rapidity of movements of the thoracic appendages of Branchipus I concluded that the appendages moved ~~slower~~ faster as the amount of oxygen decreased. Some water was thoroughly boiled and quickly cooled without re-aeration. Time of oscillations in ordinary water and in de-oxygenated water was then noted, by taking successions of counts, the number of seconds required for one hundred oscillations being in each case noted and recorded. A succession of four or five counts was taken in each kind of water alternately, a period of about two minutes being allowed after each change from one medium to the other.

These observations made April 24, 1901.

Branchipus in ordinary water, time (seconds) required to make one hundred strokes: 32; -35; -28; -32.

Same specimen in de-oxygenated water:

28 1/2; -28; -27 1/2; -29 1/2; -27 1/2.

Same specimen back in ordinary water:

33 1/2; -33 1/2; -34 1/2; -36; -33 1/2.

Same specimen in de-oxygenated water:

28; -27 1/2; -29; -28 1/2.

Same specimen in ordinary water:

35; -34; -34; -36.

Effect of Carbon-Dioxide in Water upon Rapidity of Oscillations in Appendages

In the experiments to test the effect of CO_2 on rapidity of oscillations, it was found that the oscillations are faster as the amount of CO_2 in the water is increased until a certain limit is reached, beyond which the oscillations cease altogether.

Time (in seconds) required for one hundred oscillations in ordinary water and in carbon-dioxide solution alternately was recorded.

Observations made April 25, solution of CO_2 water used was saturated the day before and had been kept corked tightly. Strength of solution uncertain.

Branchipus in 3 parts ordinary H_2O, 1 part CO_2 sol.:

24; -24 1/2; -24; -23 1/2; -23 1/2.

Back in ordinary water; observations taken immediately:

28 1/2; -29; -29 1/2; -27 1/2.

After about two minutes, still in ordinary water:

31 1/2; -31; -30; -31 1/2; -30 1/2.

In a mixture of equal parts ordinary water and CO_2 solution:

45; -oscillations almost stopped, added tap water and the Branchipus gradually revived.

April 25, 1901.

Again in tap water, using a fresh specimen of Branchipus:

23 1/2; -23; -23 1/2; -22 1/2.

Using 1 part of freshly carbon-dioxygenated water to 3 parts ordinary water:

38; -35 1/2; -41 1/2; -37; 38 1/2.

In tap water again, (after two minutes):

25; -22 1/2; -22 1/2; -22 1/2; -23.

In 1 part CO_2 solution to 5 parts ordinary H_2O:

31; -25; -23; -28 1/2; -31; -28; -28.

Observations made April 26, 1901.

Branchipus in ordinary water:

29.2; -28.6; -29.0; -28.0; -27.4; 28.0

In solution of half fresh and half CO_2 H_2O

44.8; -44.4; -41.4; -43.6.

Fresh specimen in ordinary water:

26.6; -27.2; 27.4; -26.2; 26.

Adding 1/4 part CO_2 solution:

29.6; -29.2; -29.6; -28.8; -29.

Back in ordinary water:

28.4; -28.8; -27.8; 28.8; 29.

Back in same (1/4 CO_2) mixture:

28.8; -29; -28.8.

Back in ordinary water, (after 2 min.):

26.2; -26.4; -26.8.

(Remaining observations taken April 29-May 15, 1901, exact date of each set of observations not recorded.)

Branchipus in ordinary water:

39.2; -42; -44; -43; -44.

Passed CO_2 from generator into water with Branchipus for 1 minute:

42; -43; -36; -38; -42.

Passed CO_2 another minute:

Solution was too strong, oscillations ceased almost entirely.

After several minutes in fresh water:

46; -48; -48.2; -48.

Passed in CO_2 for 45 seconds:

32; -36; -36.8; -38.2; -38.

Branchipus in ordinary water:

59; -65 (very quiet); -53 (more active); 52; -50; -55; -51; -62 (quiet in bottom of t.t.)

Added trace of CO_2 solution:

45; -44; -42; -44; 43.4.

Back in ordinary water:

55; -70 (almost no movement, very quiet).

With trace of CO_2 solution:

(and Branchipus kept in motion): 48.4; 44; 47.

(allowed to become quiet): 52; 52; 58; 60.

Different specimen, Branchipus.

In ordinary water:

38.6; -36.3; -35.6; -34; -35.2; -34.

Added trace of CO_2 solution:

46; -48.2; -45.6; -45.8.

Back in ordinary water:

41; -39.2; -39; -38; -36.4; -35; -35.

Added trace of CO_2 (less than above)

34; -32.8; -34; -33.4; -33.

Different Specimen _ Branchipus

In ordinary water:

32; -33; -31.2; -30; -31.8.

With trace of CO_2 solution added:

32; -32; -27.6 (very active); -28; -28.4; 28.4; -27.2; -26; -27.

Back in ordinary water:

36; -34; -32; -30.6; -30.4; -34.2.

With trace of CO_2 added:

27.4; -26.8; -27.

Another specimen, _ Branchipus:

In ordinary water:

In shallow dish: -26.4; -27.2; -26.2; -27.2; -27.6.

In test tube: 30.2; -29.8; -30.2; -30.4; -31.

Added trace of CO_2 sol.:

(In t.t.) 25.6; -24.8; -25; -24.6; -25.

More CO_2 added: 36.4; -38; -38.4; 38.

Back in ordinary water:

31.4; -29.8; -28; -28.4; -28.

With slight trace of CO_2 sol. added-

24.2; -24; -24; -25.2; -28.

Back in ordinary water:

30.6; -34; -38; -(quiet in bottom of test tube, -no motion.)

Different individual, _.

In ordinary water, in test tube:

25.4; -25; -23; -23.8; -23.4.

With very slight trace CO_2:

20.4; -20; -20.8; -20; -20.

Back in ordinary H_2O:

24.8; -23 (very active); -25.2; 24.8; -24.8.

With very slight trace CO_2:

21; -20.4; -20.6; -21; -20.6.

Back in ordinary water:

26; -26.4; -26; -28; 27.4; (allowed to lie quiet)

23.4; -22; 22.6; (with irritation)

26; 25.2; 25.8; (allowed to lie quiet)

21; 21.8; 22; (with irritation)

PART III

Notes on the Anatomy

Preliminary General Description

Branchipus serratus was discovered by Professor S. A. Forbes at Normal, Illinois, in April, 1876, and its external characters were described by him.

It is usually from fifteen to twenty m.m. long, and from four to six m.m. wide. Some specimens, however, were discovered in the spring of 1902 which were from thirty to thirty-five m.m. long, and from six to eight m.m. wide.

The body is distinctly divided into head and trunk. There are eleven trunk segments, bearing swimming feet, and these I shall refer to as the thorax, and the nine segments, posterior to these and without appendages, as the abdomen.

There are two pairs of antennae, the first pair belonging to the first head segment. They are simply slender clubs with about eight slender olfactory setae at the tip. (Plate II Fig.3 The second pair, together with the eyes, belong to the second head segment.

In the female the second antennae are very large at the base, and they suddenly terminate in a short slender horn. In the male the second antennae are transformed into the clasping organs and the frontal organs.

The stalked eyes are very prominent features in Branchipus, being very large compared to the size of the animal, and projecting from each side of the head for a considerable distance . The

simple eye is small and situated in the middle of the forehead. The mandibles are thick, muscular, lens shaped organs, situated on the third head segment. They are attached on the dorsal side and curve around to the ventral side, where they come together at the meridian line. The rough inner surfaces of the mandibles triturate the food by means of the continual rocking motion of the whole organ. Posterior to the mandibles on the fourth and fifth head segments are the two pairs of maxillae. They are shovel like organs, finely haired on the inner margins.

The segments of the abdomen are narrowed anteriorly, and propuced outward and backward on the posterior margins, giving the edges of the abdomen a serrate appearance, hence the name of the species.

The external pouch of the reproductive organs is situated on the first two abdominal segments. These will be described in the sections devoted to the reproductive organs.

At the posterior extremity of the abdomen is the telson, which consists of two slender, tapering stylets, as long as the last four segments of the abdomen, and plumosely haired to the base. (See Plate. V Figure 1.)

The animal is a kind of translucent gray in color, the male being much paler than the female. In the breeding season the female is brilliantly colored, with blue pigment on the top of the head, along the back, along the leg muscles, and around the external reproductive pouches. The telson and the margins of the abdomen are colored red at this time.

Development

I have not devoted much time to the study of the development, and have only taken notes of those things which could be observed without going into an exhaustive investigation.

I have sectioned specimens in which the eggs were in the early gastrula stage after they had passed over into the uterus and were surrounded by their cement covering. Whether they ever develop any further before being deposited I cannot say. The earliest stage of the Branchipus larvae that I have seen was a little later than the nauplius. (See Plate I, Fig. 1) The maxillae can be recognized, free at this time. The first pair of antennae and the stalked eyes were developed. The second pair, as well as the mandibles, are at this stage used as swimming feet, and have large lobes which are lost in the adult stage. Nine or ten of the swimming feet can be recognized, under the integument, and those nearer the anterior end are farthest advanced. All the eleven segments of the thorax can be recognized while the abdomen is as yet only one segment, with four furcal bristles on each side at the end.

By the time this larva is nine days old, as nearly as I could judge, the mandibles have lost their outer lobes and have become reduced to the stout basal segments which were described in the preliminary sketch. In this nine days old stage about five m.m. long, the second antennae have become smaller, but they have not yet assumed their adult form.

All the swimming feet are free, the nine segments of the abdomen are formed, and the furca has become simply paired plumosely haired stylets.

The external pouch of the reproductive organs is beginning to show, though the sex cannot be determined.

By the eighteenth day we have an adult Branchipus.

Integument

The study of the integument has not been at all complete. It is a delicate, structureless, chitinous covering, with comparatively few thickened places. It is thickened on the mandibles on the second joint of the claspers, on the reproductive pouches, and particularly on the paired cirri which project from these pouches in the male and form the penis, and on the lip like opening into the uterus of the female.

Claus in his description of Artemia and B. stagnalis speaks of certain pillar formed cells with large nuclei which he calls chitinogen cells. These cells form the exoskeleton and the chitinous connective tissue threads which serve as tendons for the attachment of the muscles to the outer coat. At those places where the muscles attach or where for any reason a special thickening of the integument is necessary, the chitinogen cells unite to form a basal membrane which is connected with the outer coat by a great many chitin threads. Not only is the outer coat thickened, but strengthened by these chitin threads. At other places there is no formation of a basal membrane and the muscles are attached

directly to the integument. I have seen cells which I thought corresponded to these chitinogen cells. A good illustration of them is in the swimming feet. (See Plate IV Fig.2)

Moulting

I have seen these animals moulting a number of times, and have often seen their cast skins, but although I have kept specimens isolated in order to find out how often this takes place I have been unable to do it.

They keep up a rapid vibration of the swimming feet during the process, and make frequent violent leaps, flexing and extending the abdomen.

Moulting is well illustrated in the swimming feet. (Plate IV Fig.2) The old skin is loosened, and the new hairs of the margins of the feet are formed with the basal half, or three-fifths, invaginated in the lobes of the swimming feet, and the distal end projecting into the cavity of the old hair which is everted. After moulting the invaginated portion is everted, and a distinct ring marks the extent to which it has been invaginated.

Appendages

Frontal and Clasping Organs

I need not say anything more of the head appendages, with the exception of the second antennae of the male, which have become transformed into the frontal and clasping organs. (See Plate II Fig.1)

The frontal organs of the male are considerably longer than the claspers, to the anterior inner base of which they are attached. Their form is irregularly oval, with a convex inner margin, and an outer margin which is slightly concave. These appendages taper to a slender tip which rolls up. Both margins are set with thick blunt teeth which are longest on the basal half of the outer margin, where they are as long as the appendage is wide. At the middle of this margin the teeth become suddenly shorter. The teeth are longest near the middle of the inner margin, but not so long as those of the outer, and instead of suddenly growing smaller, gradually diminish toward the ends. The entire under surface of the frontal organ is thickly set with short spines, each springing from an inflated base.

The clasping organs are situated just interior to the eyes. The basal joint is thick and soft, and has a hard rounded tubercle at its inner base. (See Plate II Fig. 1) The second joint is stout, and the inner flattened surface is concave, while opposite it is a prominent ridge, so that a cross section of the tip is T shaped. At the base is a stout spur, the round tip of which is minutely set with little circular elevations, which have minute craters at the center.

The Swimming Feet

Each of the swimming feet consists of six endite lobes, (See Plate IV Fig. 1; 1, 2, 3, 4, 5, 6), and one exite lobe consisting of the gill and the large flap (7 in Fig.). The lobes are fringed with hairs. Those hairs fringing the first two lobes are very

slender and delicate. They are themselves plumosely haired for the distal half of their length with the most delicate hairs imaginable. The basal half is haired only on one margin. The other small lobes have hairs of the same character, except that they are coarser, and there are fewer of them. The hairs of the sixth endite lobe (See Fig.2 Plate IV are stouter and shorter than those of the other lobes, and are slightly curved. The outer margin of the distal half is supplied with peculiar coarse teeth. The basal half has stiff slender bristles which are few and irregular. They are more numerous on the outer margin than on the inner, and do not extend quite to the base. The hairs of the exite lobe are very long and slender, with very fine hairs on each margin. (See Plate IV, Fig. 4.

The gill is a delicate sac like organ attached on the under side of the exite. When the foot is in motion the gill is not held under the foot as closely as is represented in the drawing.

The Nervous System

The nervous system agrees with the usual Phyllopod type. It consists of the small brain just above the oesophagus which sends off a pair of nerves straight forward to the ocellus, and very large optic nerves to the compound eyes. The first antennal nerve arises from the oesophageal commissures, and the second antennal nerve arises from the ganglia under the oesophahus which complete the oesophagial ring. Following this is the ladder like ventral chord, that is, paired chords going straight back on each side with a pair of ganglia connected by a cross commissure, arched toward the dorsal side, for each pair of

appendages. In the abdomen the paired longitudinal chords continue without the cross commissures, but they send off postero-laterally little branched twigs in each somite. (See Plate III, Fig. 4.)

Digestive and Excretory Organs

I have already described the mandibles and maxillae which keep up their continual motion immediately beneath the upper lip. The upper lip is an appendage of the first segment which comes down over the mandibles and maxillae, and which contains in a transverse row just opposite the maxillae four or five large oval glands which Claus says are salivary glands.

The mouth opening is a transverse split leading into the mouth cavity extending obliquely forward for a short distance where it enlarges into the crop. Here it bends to go straight back the entire length of the body as the intestine.

In the head of Branchipus, as is the case with Phyllopods in general, is the large two-lobed digestive gland which in external appearance is somewhat like the human brain. It consists of diverticula from the mid-gut. We can distinguish the three regions which originate from the stomodeum mesodeum and proctodeum. The walls of the fore-gut, or anterior part originating from the stomodeum have a chitinous lining back to the end of the crop, where two finger-like processes having an enlarged base, and set with papillae, extend backward into the lumen of the intestine. These are said to correspond to the gastric mill of Malacostracas.

After the fore-gut comes the mid-gut which originates from the mesodeum, and whose ephithelium is endodermic in origin. Then comes the hind-gut which originates from the proctodeum and is the same in structure as the stomodeum, and only extends for one segment. Surrounding the alimentary tract is a layer of circular muscles which serve to contract the lumen. At the posterior,

end are small muscles by which the alimentary tract is attached to the ~~lumen~~ integument, These muscles serve to enlarge the lumen. The action of these muscles can be observed very plainly under the microscope.

The excretory organs are the coiled shell glands which are situated on the dorsal wall just posterior to the mandibles. There are some cells situated interior to and partly within the cavity of the second antennae which I believe to correspond to the antennary glands of the mal ~~a~~ecostraca.

There are also some paired glands in each segment in the neighborhood of the ganglia which have peculiar nuclei which Claus compares to otoliths. He is in doubt as to whether these glands have the functions of otolith sacs, or whether they are connected with excretion. He favors the idea of their excretory function.

Circulatory System

There are two streams of blood in opposite directions. The blood flows forward in the heart and its lateral blood sinus. There is a ventral stream incompletely separated from the dorsal in which the blood flows backward.

The heart has eighteen pairs of lateral ostia. It ends in the last abdominal segment with a terminal opening. In the head region the heart becomes the head aorta without any side ostia. The blood flows from this open anterior end of the aorta to the shell glands, and the region of the maxillae, and forward over the digestive gland and to the antennae and eyes. The ventral blood sinus begins in the second trunk segment. It sends off a stream to each leg which divides, one part going down one side the exite lobes, and another part going down one side the endite lobes and back again on the other side to the ventral sinus.

The Reproductive System

The external pouch of the reproductive organs is on the first two abdominal segments. The ovaries extend from the last thoracic to the last abdominal segment. They are paired long straight tubes which begin considerably anterior to the openings into paired external sacs contained in the external pouch. Leading from this sac into the uterus, which is thick walled and muscular, are the oviducts. There are dark brown cement glands coiled in the external pouch which send ducts into the side horns of the uterus (See Plate VI Fig.4 carrying a secretion which makes the hard exterior coating of the eggs. The eggs reach the exterior through a liplike opening in the uterus. (See Plate VI Fig.1) The testes have the same extent as the ovary, and the products reach the exterior through paired openings. There is a penis which consists of two bristles. or cirri, at each opening. These are stiff and of considerable length, and during copulation are inserted in the uterus of the female. (See Plate V Fig.1)

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Description of Plates

PLATE I

Fig. 1. Larva 3 days old. a, first antennae; b, second antennae; c, mandible; d, maxillae; e, thoracic appendages; f, upper lip; g, lobes of digestive gland; h, compound eye; i, simple eye; j, alimentary tract.

Fig. 2. Head of larvae nine days old. a, first antennae; b, second antennae; c, mandibles; d, maxillae; g, digestive gland; h, compound eye; i, simple eye.

Fig. 3. Adult, male. a, frontal organ; b, clasping organ; c, mandibles; d, compound eye; e, swimming feet; f, external pouch of reproductive organs; g, digestive gland; h, shell gland.

PLATE II

Fig. 1. Clasping and frontal organs, (transformed second antennae of male). Ventral view.

Fig. 2. Dorsal view. b, basal joint of clasping organ; t, tubercle; s, spur; d, distal joint.

Fig. 3. End of first antennae, showing sensory hairs at tip.

PLATE III

Fig. 1. Frontal section through brain, showing nerves going forward to simple eye. b, brain; g, ganglion cells; n, nerves; i, simple eye. Fig. 2, simple eye.

Fig. 3. Diagram of the ventral nerve chord in two somites.

Fig. 4. Nerve chord in abdomen.

Fig. 5. Cross section of brain.

Fig. 6. Cross section of pair of thoracic ganglia and cross commissure.

PLATE IV

Fig. 1. Swimming foot. 1, 2, 3, 4, 5, 6, the six endite lobes; 7, exite lobe; 8, gill.

Fig. 2. High power drawing of hairs from sixth endite lobe. a, old hair; b, new hair; c, chitinogen cells; f, invaginated portion of new hair.

Fig. 3. Hairs from 1st endite lobe.

Fig. 4. Hairs from exite lobe.

PLATE V

Fig. 1. Ventral view of male genital organs. p, external pouch; c, cirri; t, testes; (i, the intestine; a, anus; tel, telson).

Fig. 2. Side view of male genital organs. t, testes; s, external pouch; c, cirri; d, sperm duct; o, genital opening.

PLATE VI

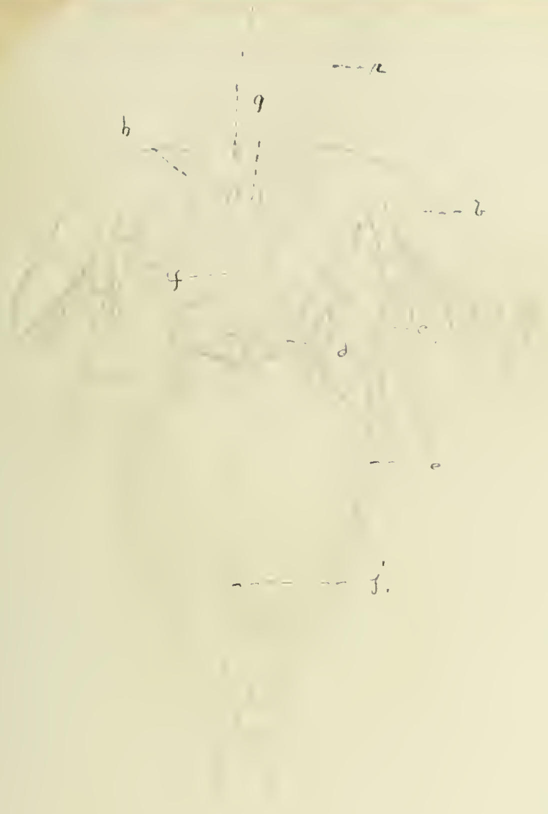
Fig. 1. Ventral view of female genital organs. c, cement glands; u, eggs in uterus; l, opening to exterior; o, ovary; p, plasmic eggs in ovary; f, food (?) cells in ovary.

Fig. 2. Cross section through uterus p, external pouch; c, cement glands; s, paired lateral sacs; m, muscles; o, ovary.

Fig. 3. p, external pouch; u, uterus; c, cem.gl.; s, lateral sacs.

Fig. 4. p, external pouch; u, uterus; c, cement glands; d, ducts leading from cement glands into side horns of uterus.

Fig. 3, Plate V. is a conventional diagram of the female reproductive organs. o, ovary; u, uterus; s, lateral sacs; p, external pouch; op, genital opening.



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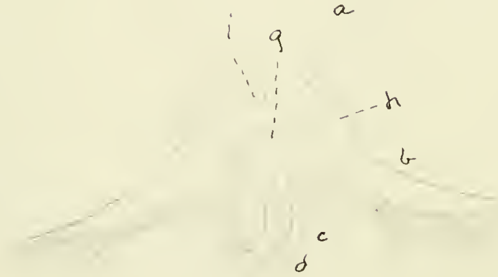

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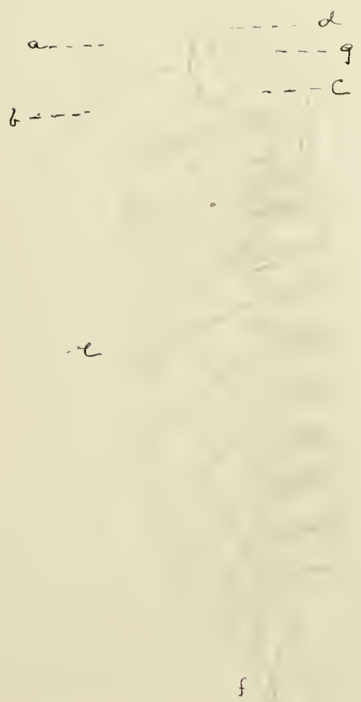

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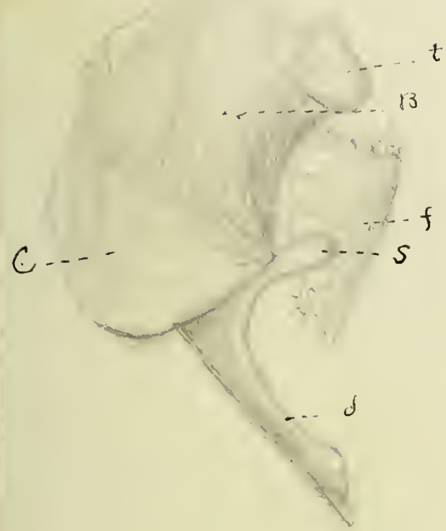

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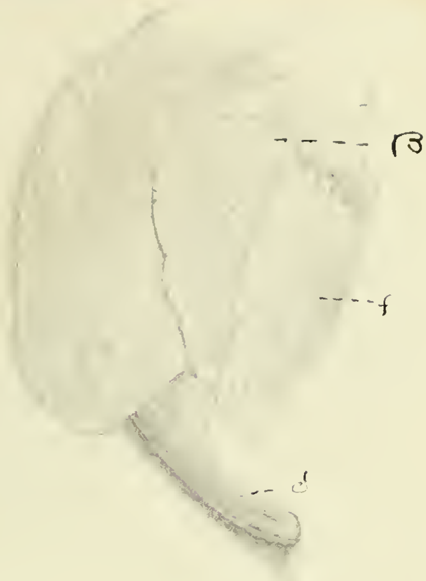

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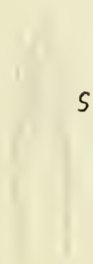

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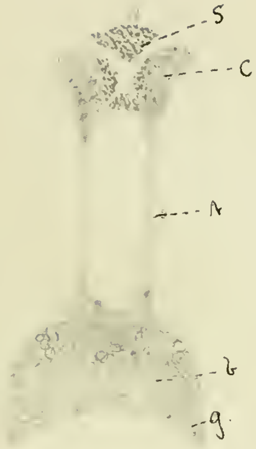

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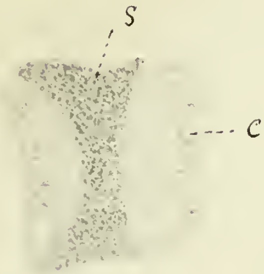

Fig. 2

Fig. 5

Fig. 3

Fig. 4

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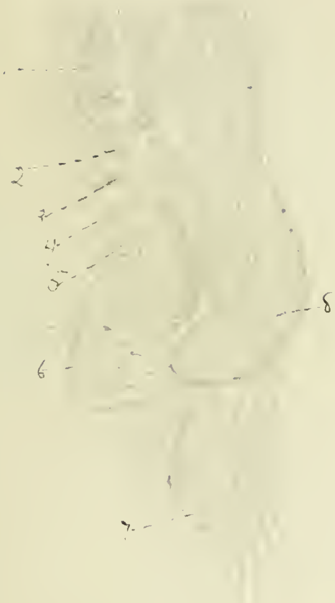

Fig. 1

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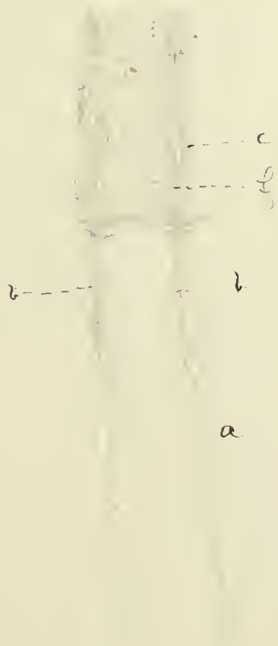

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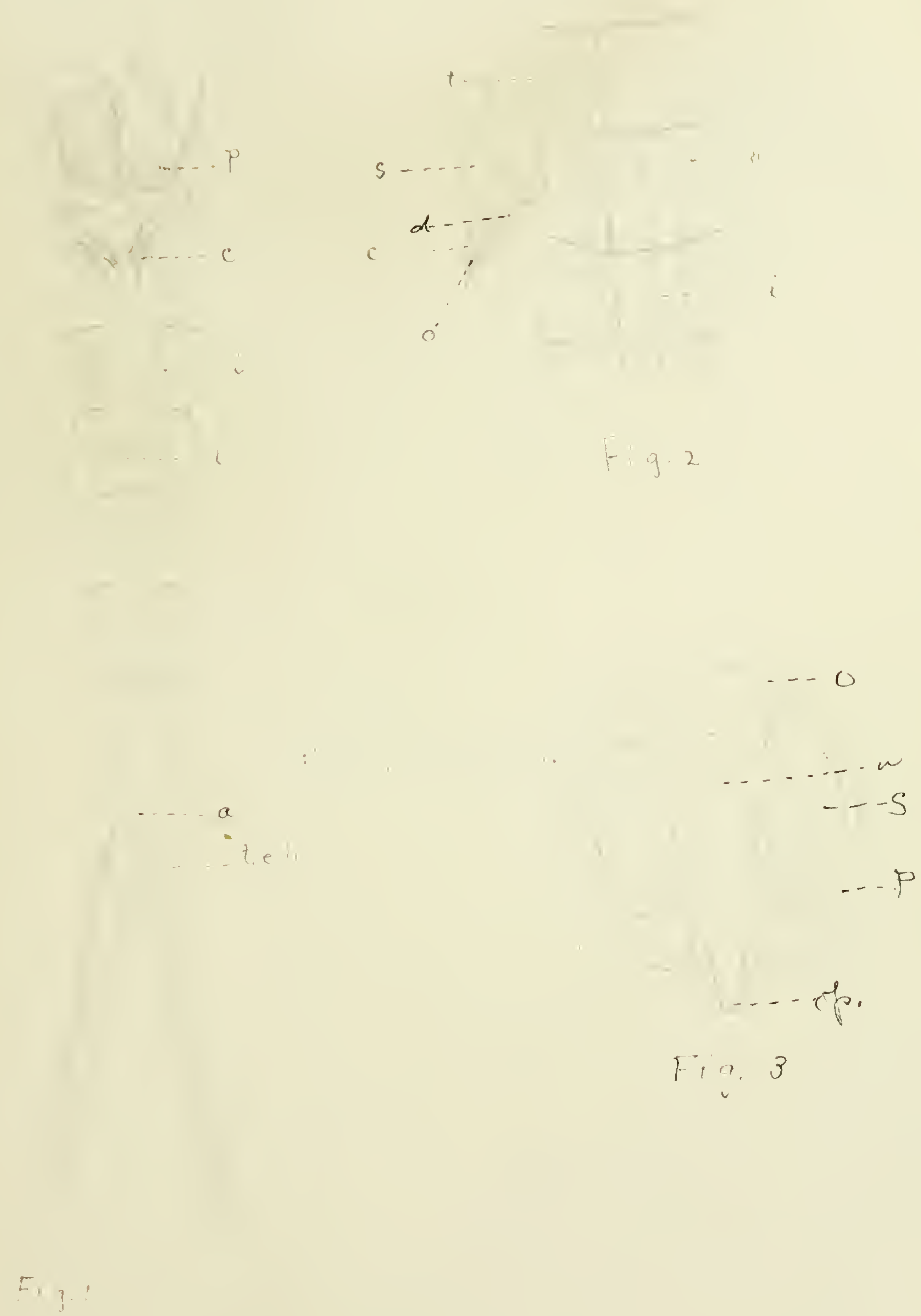
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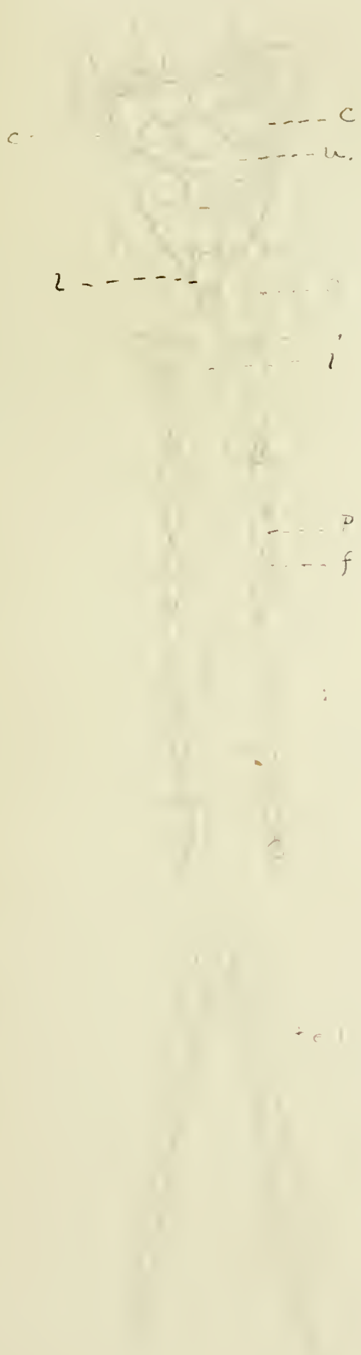

Fig. 1

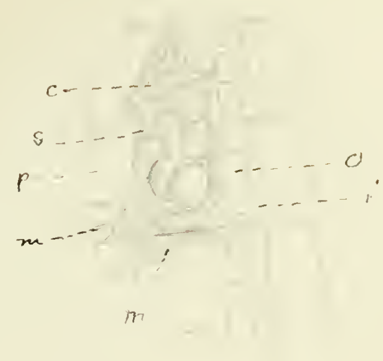

Fig. 2.

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